

Implementation of BEDSOCS: an interactive simulation language

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BEDSOCS, an interactive digital computer language that is designed to allow the easy solution of problems described by ordinary differential equations, is used to run PHYSBE (a benchmark program that simulates the human circulatory system). A comparison chart compares BEDSOCS with other simulation systems in time required to execute PHYSBE.

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Bradford Educational Simulation language for Continuous Systems (BEDSOCS), is an interactive digital computer language designed to allow the easy solution of problems described in terms of ordinary differential equations. The language uses Dartmouth BASIC as the procedural language and, like most BASIC systems, operates interpretively. BEDSOCS has such advanced features as automatic equation sorting, variable-step integration and graphic displays. The equations describing the simulation need not be represented in terms of block diagrams, but rather are entered much like ordinary differential equations. Above all, because BEDSOCS uses an interpreter, there is no compilation time. This allows users to write and debug programs quickly at the cost of longer execution time.

BEDSOCS, written by Geoffrey Brown (1973) at the University of Bradford, can be implemented on an HP2100 computer having 16k words of memory. The system uses HP BASIC as a subset and supports floating point firmware and a Tektronix storage display. Many options are available for implementing BEDSOCS. However, the authors used a single user version distributed on paper tape. Using BASIC as a subset, BEDSOCS partitions a program into a *control region*, which contains BASIC statements, and a *dynamic region*, which describes the representation of the system to be simulated. In the control region the user can program in BASIC to establish initial conditions, set control variables and perform general computation and input/output. The dynamic region contains the representation of the set of differential equations (see Fig. 1).

The control region is divided into the *initial region* and the *terminal region*. The initial region precedes the dynamic portion of the BEDSOCS program and is used to set initial conditions and control variables to be used in the dynamic region. The terminal region is executed when the simulation is completed. This region is generally used to perform final calculations, print results, or loop back for iterative differential equation solving runs. The dynamic region of a BEDSOCS program contains the 'representation set'. This is a set of equations and procedure blocks representing the simulation to be performed. Fig. 2 shows a typical procedure block, enclosed by the 'PROCED' and 'PROEND' statements. The 'PROCED' statement has the form:

<statement no.> PROCED <output list> = <input list>

where the <input list> contains the dependent variables used within the procedure block and the <output list> contains the dependent variables which are assigned values by the procedure block. Within a procedure block, the user may describe non-linear functions or other operations involving any BASIC statement just as in the control region. There may be any

number of procedure blocks within a BEDSOCS program. However, a variable may not occur in the output list of two procedure blocks. Inputs and outputs of procedure blocks are sorted just like those of a defined variable equation.

Equations of the representation set differ from BASIC statements in their location and form. These statements are not preceded by the 'LET' identifier of BASIC and they are automatically sorted into a BASIC program which evaluates derivatives and then updates state variables (integration). For example, the following differential equation may be expressed in BEDSOCS with the aid of the 'DER' identifier.

$$dx^2/dt^2 - 5x + 3 = y$$

In BEDSOCS

```
300 DER Z = Y - 5 * X + 3
310 DER X = Z
or
300 W = 5 * X - 3
310 DER Z = Y - W
320 DER X = Z
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These simple equation statements combined, if necessary with procedure blocks, make it very easy to describe complex systems. Since BEDSOCS is interpretive, it is executed without compilation. When the user types 'RUN', BEDSOCS checks the program structure, creates the symbol table, sorts the representation set and initialises the independent variable or variables to zero. As this initial setup is performed, errors are displayed on the user's console with the number of the line where the error occurred. Execution continues procedurally

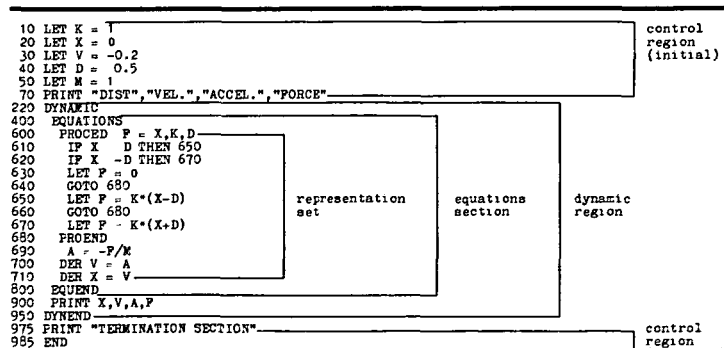


Fig. 1 The regions of a typical BEDSOCS program (Brown, 1973)

```
600 PROCED P = X,K,D
610 IF X > D THEN 650
620 IF X < -D THEN 670
630 LET P = 0
640 GOTO 660
650 LET P = K*(X-D)
660 GOTO 680
670 LET P = K*(X+D)
680 PROEND
```

Fig. 2 A typical BEDSOCS procedure block

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through the control region until the dynamic region is encountered. At that time, the integration routines are initialised and execution continues into the dynamic region. The dynamic

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1 REM: PROJ. OVER WALL
10 READ G,P,G1,G2,V0,A0,E0
30 DATA 9.8,1.0000E-02,.6,.6,50,45,.5
40 PRINT "RANGE":
45 INPUT R
48 LET @[?] := @[?] - E0 0
49 LET @[?] := @[?] - R
55 PRINT "DIST. & HEIGHT OF WALL":
60 INPUT W,H
77 LET A0=ATN(1)A0/45
100 LET V1=V0-COS(A0)
105 LET V2=V0-SIN(A0)
110 LET V=SGN(V1+V2+1)
125 LET A=ATN(V2/V1)
130 LET V0=V
135 LET A0=A
140 LET X=Y=T=0
150 LINE W,0,W,H
200 DYNAMIC
210 EQUATIONS
220 INVAR T
223 DER V=-G*SIN(A)-P*V 2
227 DER A=-(G/V)*COS(A)
230 DER X=V-COS(A)
240 DER Y=V-SIN(A)
250 EXIT (X > W)
260 EXIT (Y < 0 AND X > 0)
450 DISPLAY X,Y
550 EQUEND
560 IF Y < 0 GOTO 600
570 LET Z=Y
580 DYEND
600 LET E1=R-X
610 LET E2=H-Y
620 IF ABS(E1)+ABS(E2)<E0 THEN 650
630 LET V1=V1-G1*E1
635 LET V2=V2-G2*E2
640 GOTO 110
650 PRINT "TIME", "HEIGHT AT WALL", "RANGE", "SPEED", "ANGLE"
660 PRINT T,Z,X,V0,A0+45/ATN(1)

```

Fig. 3 A BEDSOCS program to calculate the path of a projectile

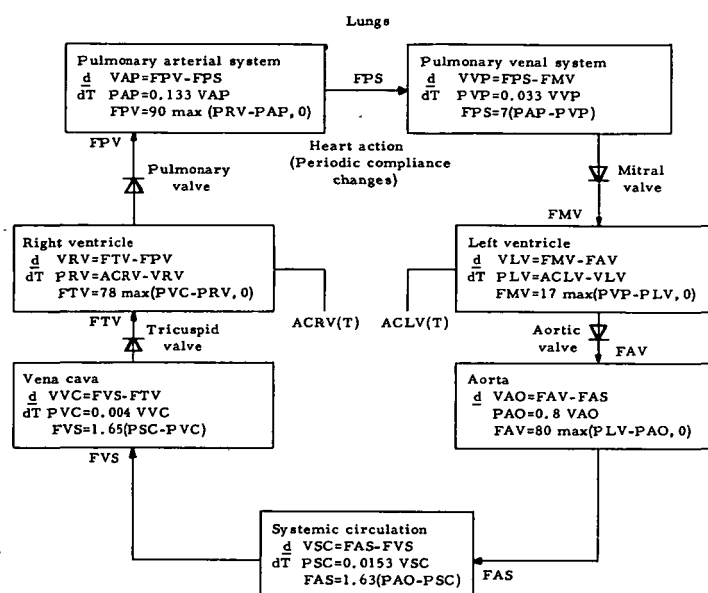


Fig. 4 A block diagram of the PHYSBE model (Korn and Wait, 1976)

Table 1

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PAGE 0001      *PHYS3      19 MAY 1978      00:10:12

0001 20 REM ***** PHYSBE *****
0002 40 REMARK
0003 60 REM
0004 100 VARIABLE EQUIVALENCES
0005 120 P1=1 P2=2 P3=3 P4=4 P5=5 P6=6 P7=7
0006 140 P8=8 P9=9 P10=10 P11=11 P12=12
0007 160 P13=13 P14=14 P15=15 P16=16 P17=17
0008 180 P18=18 P19=19 P20=20 P21=21 P22=22
0009 200 P23=23 P24=24 P25=25 P26=26 P27=27
0010 220 P28=28 P29=29 P30=30 P31=31 P32=32
0011 240 P33=33 P34=34 P35=35 P36=36 P37=37
0012 260 P38=38 P39=39 P40=40 P41=41 P42=42
0013 280 P43=43 P44=44 P45=45 P46=46 P47=47
0014 300 P48=48 P49=49 P50=50 P51=51 P52=52
0015 320 P53=53 P54=54 P55=55 P56=56 P57=57
0016 340 P58=58 P59=59 P60=60 P61=61 P62=62
0017 360 P63=63 P64=64 P65=65 P66=66 P67=67
0018 380 P68=68 P69=69 P70=70 P71=71 P72=72
0019 400 P73=73 P74=74 P75=75 P76=76 P77=77
0020 420 P78=78 P79=79 P80=80 P81=81 P82=82
0021 440 P83=83 P84=84 P85=85 P86=86 P87=87
0022 460 P88=88 P89=89 P90=90 P91=91 P92=92
0023 480 P93=93 P94=94 P95=95 P96=96 P97=97
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0026 540 P105=105 P106=106 P107=107 P108=108
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0269 5400 P1077=1077 P1078=1078 P1079=1079 P1080=1080
0270 5420 P1081=1081 P1082=1082 P1083=1083 P1084=1084
0271 5440 P1085=1085 P1086=1086
```

Table 2 Comparison of execution times (based on Korn and Wait, 1976)**(a) Batch-Processed, Equation-Oriented, Floating-Point Languages, Large Computers**

<i>System</i>	<i>Computer</i>	<i>Integration Routine</i>	<i>Execution Time (sec)</i>
FORTRAN	CDC 3600	Not known	2
CSMP III	IBM 360/50	Not known	1.46
	IBM 360/65	Not known	0.42
DARE P	CDC 6400	Runge-Kutta 2	0.16
		Runge-Kutta-Merson (0.001 rel. error)	0.91
RSSL	CDC 6600	Runge-Kutta 2	0.056

(b) Interactive, Equation-Oriented, Floating-Point Language, Minicomputers

DARE/ELEVEN	DEC PDP-11/40		
	Floating-point software (DOS)	Runge-Kutta 2	6.5
	Floating-point firmware (RT-11)	Runge-Kutta 2	3.6
	DEC PDP-11/45		
	Core memory, floating-point software (DOS)	Runge-Kutta 2	4.5
	Bipolar memory, floating-point hardware	Runge-Kutta 2	< 1.2* estimated

(c) Interactive, Block-Diagram, Floating-Point Languages, Minicomputers

Block CSMP	IBM 1130		
	Interpreter mode	Runge-Kutta 2	40
	Compiler mode	Runge-Kutta 2	20
	DEC PDP-11/45	Not known	14.6
	FP software only		
ISL-11†	DEC PDP-11/20	Euler	1.4
	DEC PDP-11/45	Runge-Kutta 2	2.8
	FP software only	Euler	0.6

(d) Interactive, Block-Diagram, Fixed-Point Languages, Minicomputers (with hardware multiplication)

DARE II	DEC PDP-9	Runge-Kutta 2	0.9
DARE/ELEVEN	DEC PDP-11/40	Runge-Kutta 2	0.19
	DEC PDP-11/45	Runge-Kutta 2	0.06 estimated
	bipolar memory		
MICRODARE	DEC PDP-11/40	Runge-Kutta 2	0.3
	DEC PDP-11/03	Runge-Kutta 2	0.9

(e) Interactive, Equation-Oriented, Fixed-Point Language with Semiautomatic Scaling, Minicomputers (with hardware multiplication)

SIMEX	DEC PDP-9	Euler	0.19
	DEC PDP-15	Euler	0.15 estimated
BDARE	PDP-11/40	Runge-Kutta 2	31
(BASIC)	no FP firmware		
BEDSOCS	HP 2100 with FP	Runge-Kutta Merson 4th order	22

region is split into two sections, a procedural part and the representation set.

When control flows into the dynamic region, it encounters the first procedural section. This region (transparently to the user) repeats derivative calls and integration steps as determined by the derivative computing routine, defined by procedure blocks and equations within the representation set. This routine is executed until a communication point is encountered. Such points occur at regular intervals set by the user in the control region, or at points determined by test values described by 'EXIT' statements. When a communication point occurs, execution is transferred to a procedural section of the dynamic region following the equations section of the program, typically to produce output. Fig. 3 shows a program which uses the communication points by means of the 'EXIT' statement. When the value of the inequality in the 'EXIT' statement

changes from 'FALSE' to 'TRUE', the program transfers control to the procedural section following the representation set as shown.

BEDSOCS uses a 4th order Runge-Kutta-Merson integration routine which allows variable step sizes. By using control variables, the user can set the error tolerance and the minimum step size. As the simulation continues, the step size is adjusted according to the estimated truncation error.

In a variable step integration, the user does not choose the values of the independent variable at which solutions are evaluated. For example, Fig. 3 shows a program which finds the initial angle and velocity necessary for a projectile to pass over a wall and hit a target on the other side. For this procedure it is necessary to know the altitude of the projectile as it passes over the wall. The 'EXIT' statement in line 250 causes the integration routine to back up and hit the point where X becomes

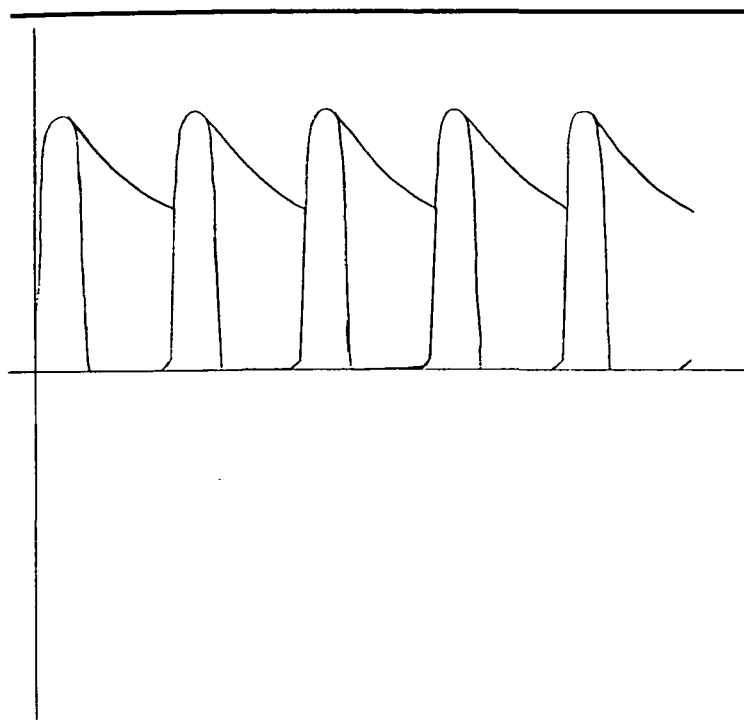


Fig. 5

greater than or equal to W . In this way particular points may be evaluated while areas of lesser interest may be passed over using larger integration steps.

The BEDSOCS display system is completely automatic. To display the variable X as it is evaluated, it is only necessary to place a 'DISPLAY X ' statement in the equation section of the program. This will display X as a function of the independent variable as the simulation is performed. The axis values are

References

- BROWN, G. (1973). BEDSOCS MARK I Reference Manual, Postgraduate School of Studies in computing, University of Bradford, August 1973.
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oriented processing system (CHEOPS) illustrates the seminal influence of AI on computer science. It describes special hardware to deal with the search part of chess programs, it makes practical a depth of 8 or 9 while experimenting with different heuristic strategies. The special hardware is front ended by conventional computers to relieve it of I/O and housekeeping. The short paper includes a description of the facilities used to design and fabricate the hardware. There are 16 accumulators, a 1024 words pushdown list, a chess array module to carry out as single instructions standard checks, moves and other operations; microcode is used. The paper by Arlazarov and Futer is concerned with the king rook pawn against king rook end game. Data structures are developed to minimise storage and processing, symmetries and other properties are used to cut down further the number of cases (about 10^9). Starting with the end positions the resulting reduced set is generated iteratively and classified into win or draw with the appropriate move. The paper by Adelson-Velsky, Arlazarov and Donskoy on algorithms of adaptive search in computer chess uses influence relations to construct mathematical expressions in terms of graphs and trees for various situations such as attack, pin, check, etc. The results of various searches are stored using appropriate data structures.

The first paper in the section on knowledge engineering is by Buchanan on issues of representation in conveying the scope and limitations of intelligent assistant programs. The paper starts with a brief description of DENDRAL, the famous expert system to aid chemists in determining chemical structures. The main modules include CONGEN which generates a large number of possible

generally set in the control region of the program, but they may be dynamically altered through the communication (procedural) sections or the procedure blocks. BEDSOCS automatically draws the axes and plots a multiplicity of lines. For example, 'DISPLAY T ; A , B , C ' draws the variables A , B , and C against the variable T throughout the simulation. Although only one display statement may be active at a time, special 'USE' statements allow a choice among several display statements. Each statement is activated at a different time during the execution.

In order to measure the execution times for BEDSOCS programs, PHYSBE, a well known benchmark program (Korn and Wait, 1976), was used. This program simulates the human circulatory system. Fig. 4 contains a diagram of the seven differential equations describing blood flow. The system is driven by the two chambers of the heart, represented by a table of values (Table 1). Table 2 shows how BEDSOCS compares with other simulation systems in time required to execute PHYSBE. Although BEDSOCS is comparatively slow (execution time of 22 seconds per heart beat), its interpretive features greatly reduce development time. Fig. 5 is a sample PHYSBE execution.

Perhaps the most significant feature of BEDSOCS is the ease with which it can be mastered. Using BASIC as a procedural language and implementing the representation set in a familiar format allows even the novice to write complex simulation programs. BEDSOCS not only requires no compilation time, but also greatly simplifies debugging. For users requiring immediate response on small problems, BEDSOCS is an attractive simulation language.

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structures consistent with the given chemical and spectroscopic data, the planner which interacts with the chemist to make use of his expert knowledge, and the meta-dendral which makes use of the accumulated structure-spectrum data to formulate new rules to explain the behaviour of compounds. The paper concentrates on the internal representation most suitable in communicating with the users and experts, documentation issues, and communicating the progress of the computation in the form of a laboratory notebook including a trace of the reasoning steps. The second paper by Briabrin describes the internal structure of DILOS, the system described in the paper by Pospelov and Pospelov above. It consists of a set of LISP programs to set up and search a data base, initiation of application programs, logical analysis of the problem area, and consistency checking of new facts added to the data base.

The final section is on natural language and the first paper on natural language for interaction with a data base by Senin is also on DILOS. It is concerned with the linguistic processor module which developed the ϕ -language for user communication with the system. The paper by Narin'jani describes the AI work in the Siberian branch of the USSR academy of sciences. This concentrates on the nondeterministic behaviour model in robot control and formal models, semantic representation and interrogation methods in the area of natural languages. The final paper is on purposive understanding by Schank and DeJong. It starts with a short and clear review of the various stages of developing the SAM computer system to understand natural language, then describes in more detail a new system, FRUMP, which concentrates in a top down fashion on selective rather than total understanding.

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